Supplementary Material

Table 1. List of putative welfare indicators of relevance to the assessment of sheep welfare derived from the literature and expert assessment. Indicators are animal based unless otherwise stated, applicability refers to the categories of animals to which these indicators are restricted.

| Welfare Principle[1] | Welfare Criteria[1] | Indicator | Applicability | Source |
|---|---|---|---|---|
| Good Feeding | Absence of prolonged hunger | Body Condition Score | Handled animals | Russell et al., 1969; Caldiera et al., 2007; Pines et al., 2007; Morgan-Davies et al., 2008; Stubsjoen et al., 2011 |
| | | Tooth loss | Handled animals | McGregor, 2011 |
| | | Lamb survival[3] | Farm records | Pines et al., 2007; Veksler et al., 2008; Stott et al., 2012 |
| | Absence of prolonged thirst | Skin pinch test[4] | Handled animals | |
| | | Plasma/urine sample, plasma proteins etc. | Handled animals | Lowe et al., 2002; Pines et al., 2007; Tadich et al., 2008 |
| | | Access to water[4] | Resource-based | |
| Good Environment [2] | Comfort around resting | Lying time | Undisturbed animals | Bøe et al., 2006 |
| | | Lying synchrony | Undisturbed animals | Bøe et al., 2006; Pines et al., 2007; |
| | | Coat cleanliness | Handled and Undisturbed animals | Napolitano et al., 2008; Caroprese et al., 2009; Stubsjoen et al., 2011 |
| | Thermal comfort | Respiration rate/panting | Undisturbed animals | Lowe et al., 2002; Sevi et al., 2002; |

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| | | | | Pines et al., 2007; Lovatt, 2010; Phythian et al., 2012 |
| | | Shivering | Undisturbed animals | Phythian et al., 2011 |
| | | Rectal temperature | Handled animals | Lowe et al., 2002; Sevi et al., 2002; Lovatt, 2010 |
| | | Blood or urine measures of haematocrit, plasma protein etc. | Handled animals | Lowe et al., 2002; Pines et al., 2007; Tadich et al., 2008 |
| | | Access to shade and shelter | Resource-based | Lin et al., 2012; Caroprese et al., 2012; Pollard 2006 |
| | Ease of movement | Stocking density | Housed animals only, Resource-based | Pines et al., 2007; Caroprese et al., 2009; Averos et al., 2014 |
| | | Floor slipperiness | Housed animals only; Resource-based | Napolitano et al., 2009 |
| | | Aggression and displacements | Housed animals only | Faerevik et al 2005; Lauber et al 2012 |
| | | Hoof overgrowth | Housed animals only | Caroprese et al., 2009; Napolitano et al., 2009 |
| Good Health | Absence of injuries | Integument alterations | Handled animals | Caroprese et al., 2009; Napolitano et al., 2009; Lovatt, 2010; Stubsjoen et al., 2011; |
| | Absence of disease | Lameness (gait score) | Handled and undisturbed | Caroprese et al., 2009; Napolitano et |

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| | | | animals | al., 2009; Kaler et al., 2009; 2011; Stubsjoen et al., 2011; Phythian et al., 2012; 2013 |
| | | Faecal soiling of breech area (dag score) | Handled and undisturbed animals | Caroprese et al., 2009; Lovatt, 2010; Stubsjoen et al., 2011; Phythian et al., 2012 |
| | | Faecal egg count | Handled animals | Caroprese et al., 2009 |
| | | Wool and skin condition/irritation | Handled animals | Caroprese et al., 2009; Napolitano et al., 2009; Lovatt, 2010; Stubsjoen et al., 2011; Phythian et al., 2012 |
| | | Mucosa colour | Handled animals | Bath & van Wyk, 2009 |
| | | Eye conditions | Handled animals | Lovatt, 2010; Stubsjoen et al., 2011 |
| | | Eye discharge | Handled animals | Lovatt, 2010 |
| | | Hampered respiration | Handled animals | Lovatt, 2010; |
| | | Coughing | Handled animals | Stubsjoen et al., 2011; Phythian et al., 2012 |
| | | Nasal discharge | Handled animals | Lovatt, 2010; Stubsjoen et al., 2011 |
| | | Swollen joints or callus | Handled animals | Lovatt, 2010; Stubsjoen et al., 2011 |
| | | Udder symmetry | Handled animals | Lovatt, 2010 |
| | | Udder lesions | Handled animals | Lovatt, 2010 |

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| | | Udder temperature | Handled animals | Lovatt, 2010 |
| | | Presence of udder fibroids | Handled animals | Lovatt, 2010 |
| | | Milk somatic cell count | Dairy sheep only | Caroprese et al.,2009; Lovatt, 2010; Fragkou et al., 2014 |
| | Absence of pain induced by management procedures | Ear damage caused by identification procedures (notches, tears etc.) | Handled animals | Stubsjoen et al., 2011 |
| | | Tail docking – absence of full tail | Undisturbed animals | Napolitano et al., 2009 |
| | | Teeth grinding (non-specific pain) | Handled animals | Braun et al., 1992; Kania et al., 2006 |
| | | Social withdrawal | Undisturbed animals | Phythian et al., 2011 |
| | | Pain facial expression | Undisturbed animals | McLennan et al., 2016 |
| | | Pain postures (abnormal, hunched, trembling) | Undisturbed animals | Hughan et al., 2001; Kania et al., 2006; Colditz et al., 2010; Edwards et al., 2011 |
| Appropriate Behaviour | Expression of social behaviours | Social withdrawal | Undisturbed animals | Phythian et al., 2011 |
| | | Vocalisations | Undisturbed animals | Boissy and Dumont, 2002; Cockram, 2004; Da Costa et al., 2004; Pedernera-Romano et al., 2011 |
| | | Behavioural synchrony | Undisturbed animals | Dwyer, 2004 |
| | Expression of other behaviours | Abnormal behaviour | Undisturbed animals | Dwyer and Bornett, 2004 |
| | | Vigilance | Undisturbed animals | Boissy and Dumont, |

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| | | | | 2002; Dwyer, 2004; Lee et al., 2016 |
| | | Response to surprise | Undisturbed animals | Dwyer, 2004 |
| | | Novel object test | Handled animals | Forkman et al., 2007; Pedernera-Romano et al., 2011; Destrez et al., 2013 |
| | Good human animal relationship | Human approach test | Undisturbed animals | Hutson, 1982; Waiblinger et al., 2006 |
| | | Fear test | Housed animals | Lankin, 1997 |
| | | Response to milking | Dairy sheep only | Lyons, 1989 |
| | Positive emotional state | Qualitative Behavioural Assessment (QBA) | Undisturbed animals | Wemelsfelder and Farish, 2004 |
| | | Play behaviour | Undisturbed animals | Dwyer, 2004 |

[1]After Welfare Quality (Keeling et al., 2008)
[2]Adaptation of original Welfare Quality criteria to meet extensively managed animals.
[3]Lamb survival is not considered to be specific for this criterion.
[4]These indicators were not present in the literature but suggested by the authors on the basis of their knowledge of sheep/other species.

Table 2. List of putative indicators of sheep welfare, summarising the evidence associated with validity, reliability and feasibility

| Indicator | Validity | Reliability | Specificity | Feasibility | Comments |
|---|---|---|---|---|---|
| Body Condition Score | Yes | Inter-observer good; intra-observer not tested | Moderate | Yes, requires handling | Undernutrition frequently cited as one of the most important welfare issues for extensively manage sheep |
| Tooth loss | Yes | Not tested | Good | Yes, requires handling | |
| Lamb mortality | Yes | Relies of farm records | Not specific | Yes | Potential ice-berg indicator |
| Skin pinch test | Not tested in sheep | Not tested | Unknown | No | |
| Access to water | Yes | Not tested | Moderate | Yes | |
| Lying time | Yes | Not tested | Not specific | Moderate | Feasible only in housed animals or small paddocks; may require long observation periods |
| Lying synchrony | Yes | Not tested | Not specific | Yes | |
| Coat cleanliness | Yes | Very good | Good | Yes | |
| Respiration rate/panting | Yes | Not tested | Good | Yes | |
| Shivering | Yes | Not tested | Good | No | Very low rate of occurrence in adult sheep |
| Rectal temperature | Moderate | Not tested | Moderate | No | |
| Access to shade and shelter | Yes | Not tested | Good | Yes | |
| Stocking density | Yes | Not tested | Good | Yes | Only suitable for housed |

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| | | | | | animals |
| Floor slipperiness | Not tested | Very good | Moderate | Yes | Only suitable for housed animals |
| Aggression and displacements | Yes | Not tested | Moderate | Yes | Only suitable for housed animals |
| Hoof overgrowth | Moderate | Yes | Not specific | Yes | Only suitable for housed animals |
| Integument alterations | Yes | Yes | Good | Yes | |
| Lameness | Yes | Yes | Good | Yes | |
| Faecal soiling of breech | Yes | Yes | Moderate | Yes | |
| Faecal egg count | Yes | Yes | Good | No | |
| Wool/skin condition | Yes | Yes | Moderate | Yes | |
| Mucosa colour | Yes | Moderate | Good | Yes | |
| Eye condition | Yes | Not tested | Good | Yes | |
| Eye discharge | Yes | Not tested | Good | Yes | |
| Hampered respiration | Yes | Not tested | Good | Yes | |
| Coughing | Yes | Not tested | Good | Yes | |
| Nasal discharge | Yes | Not tested | Good | Yes | |
| Swollen joints/callus | Yes | Poor | Good | Yes | |
| Udder symmetry | No | Not tested | Poor | Yes | |
| Udder lesions | Yes | Not tested | Good | Yes | Generally low incidence |
| Udder temperature | Yes | Not tested | Moderate | Yes | |
| Presence of udder fibroids | Yes | Not tested | Good | Yes | Generally low incidence |
| Ear damage | Yes | Not tested | Good | Yes | Tagging is a legal requirements in many countries, only assess |

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| | | | | | damage associated with poor practice. |
| Tail docking – absence of full tail | Yes | Not tested | Good | Yes | Tail docking legal in many countries, only assess compliance with the law. |
| Teeth grinding | Yes | Not tested | Good | No | Potentially feasible at group level only |
| Social withdrawal | Yes | Not tested | Not specific | Yes | |
| Facial expression | Yes | Yes | Good | Moderate | |
| Pain postures | Not tested in adult sheep | Not tested | Moderate | Yes | |
| Vocalisations | Yes | Not tested | Poor | Moderate | Feasible at group level only |
| Behavioural synchrony | Yes | Not tested | Poor | Yes | |
| Abnormal behaviour | Yes | Not tested | Good | Moderately | Generally very low incidence |
| Vigilance | Yes | Not tested | Poor | Yes | |
| Response to surprise | Yes | Not tested | Moderate | Moderately | |
| Novel object test | Yes | Not tested | Moderate | No | Between farm variation in feasibility |
| Human approach test | Yes | Not tested | Good | Yes | |
| Fear test | Yes | Repeatability good, reliability not tested | Good | Yes | Housed animals only |
| Response to milking | Yes | Repeatability good, reliability not tested | Moderate | Moderately | Dairy animals only |
| Qualitative Behavioural | Yes | Yes | Not specific | Yes | |

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| Assessment (QBA) | | | | | |
| Play behaviour | Yes | Not tested | Good | No | Low play incidence in adult animals |

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